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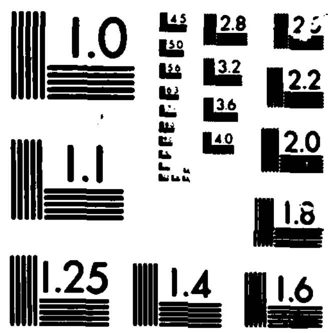

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M. M. Weiner

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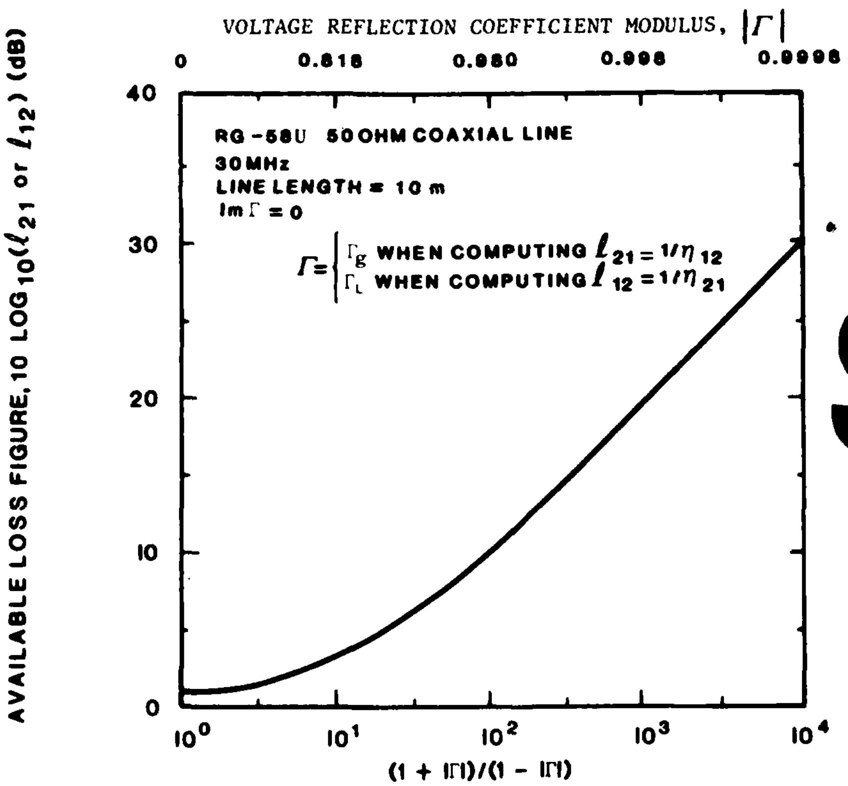

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Exact expressions for the available loss factor, noise factor, and efficiency of a distributed linear transmission line are presented for arbitrary mismatch of its source and load impedances to the line's characteristic impedance. Numerical results are given for a low-loss coaxial line.

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Source Impedance
Transmission Line
Transmission Line Length
Two-Port Network
Voltage Reflection Coefficient

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M. M. Weiner

Available Loss Factor, Noise Factor, and Efficiency of a Mismatched Transmission Line

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Abstract

Exact expressions for the available loss factor, noise factor, and efficiency of a distributed linear transmission line are presented for arbitrary mismatch of its source and load impedances to the line's characteristic impedance. Numerical results are given for a low-loss coaxial line.

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For a distributed linear transmission line (see figure 1) with a matched source and load, the available loss factor ℓ, noise factor f referenced to an arbitrary noise temperature T_{ref}, and efficiency η are related and given by [(1)-(3)]

$$\ell = f = 1/\eta = \exp(2\alpha d);\ Z_g = Z_L = Z_o^*,\ T_n = T_g = T_{ref} \qquad (1)$$

where

α = line's attenuation constant (nepers/m)

d = length of the line (m)

Z_g, Z_L = impedances of the source and load, respectively (ohms)

Z_o = characteristic impedance of the line (ohms)

T_g, T_n = ambient temperatures of the source impedance and line, respectively.

The purpose of this letter is to give exact expressions and numerical results of ℓ, f, η for arbitrary mismatch of the source and load impedances to the line's characteristic impedance.

The available loss factor ℓ of a passive linear two-port network is defined as[(1)]

$$\ell_{21} = s_{i1}/s_{o2},\ 1 \le \ell_{21} \le \infty \qquad (2)$$

where s_{i1} and s_{o2} are the available powers at the input port 1 and output port 2, respectively. The subscript 21 denotes that the input port is port 1 and the output port is port 2. The available loss factor ℓ_{21} is a function of the source impedance and output impedance (looking back at the input) but not its load impedance. Generally, $\ell_{21} \ne \ell_{12}$ unless $Z_g = Z_L$ or the network is lossless (contains no dissipative elements) in which case $\ell_{21} = \ell_{12} = 1$.

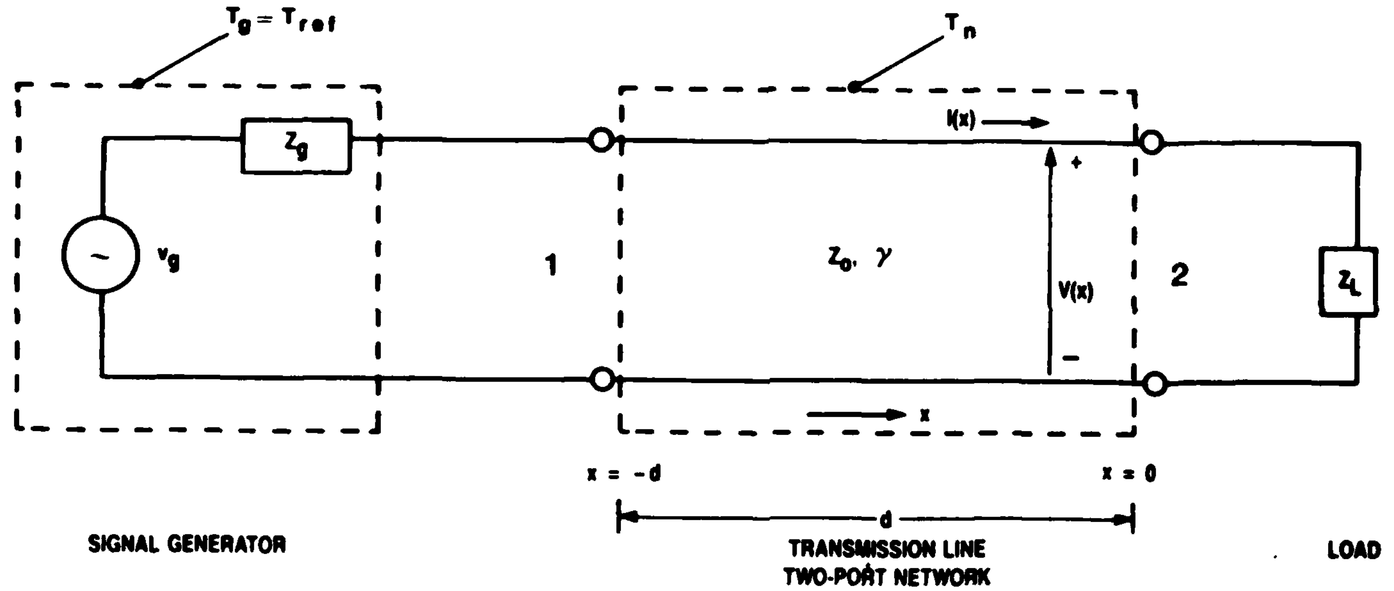

Figure 1. Transmission Line Two-Port Network

For the transmission line of figure 1, ℓ_{21} is given by[4]

$$\ell_{21} = \frac{\exp(2\alpha d)\left|1 - |\Gamma_g|^2 \exp(-4\alpha d) - 2[\mathrm{Im}(Z_o)/\mathrm{Re}(Z_o)]\mathrm{Im}[\Gamma_g \exp(-2\gamma d)]\right|}{1 - |\Gamma_g|^2 - 2[\mathrm{Im}(Z_o)/\mathrm{Re}(Z_o)]\mathrm{Im}\Gamma_g} \tag{3}$$

where

$\gamma = \alpha + j\beta$ = line's propagation constant

$\Gamma_g = [(Z_g/Z_o) - 1]/[(Z_g/Z_o) + 1]$ = voltage reflection coefficient of signal generator

For $\Gamma_g = 0$, $\ell_{21} = \exp(2\alpha d)$.

The line's noise factor f is related to the line's available loss factor ℓ_{21} by [2]

$$f = 1 + (\ell_{21} - 1)(T_n/T_{ref}),\ T_g = T_{ref} \tag{4}$$

where T_n, T_g, T_{ref} are defined in Eq. (1). For $T_n = T_{ref}$, Eq. (4) reduces to

$$f = \ell_{21},\ T_n = T_g = T_{ref} \tag{5}$$

The line's efficiency η is defined as[3]

$$\eta_{21} = p_{o2}/p_{i1},\ 0 \leq \eta_{21} \leq 1 \tag{6}$$

where p_{i1} and p_{o2} are the net transmitted time-averaged powers at the input port 1 and output port 2, respectively. The efficiency η_{21} is a function of the load impedance and input impedance but not its source impedance.

For a sinusoidal excitation, the net transmitted time-averaged power p(x) at an arbitrary position x along the line is given by [3],[5]

$$p(x) = \frac{1}{2} G_o |V_+|^2 \exp(-2\alpha x) \left\{ 1 - |\Gamma_L \exp(2\gamma x)|^2 + 2 \frac{B_o}{G_o} \operatorname{Im}[\Gamma_L \exp(2\gamma x)] \right\} \tag{7}$$

where

V_+ = complex voltage amplitude of the forward traveling wave at $x = 0$

$\Gamma_L = [(Z_L/Z_o) - 1]/[(Z_L/Z_o) + 1]$ = voltage reflection coefficient of load

$G_o = \operatorname{Re}(1/Z_o)$

$B_o = \operatorname{Im}(1/Z_o)$

Noting that $B_o/G_o = -\operatorname{Im}(Z_o)/\operatorname{Re}(Z_o)$, $p_{o2} = p(0)$, and $p_{i1} = p(-d)$, the efficiency η_{21} is given by

$$\eta_{21} = \frac{1 - |\Gamma_L|^2 - 2[\operatorname{Im}(Z_o)/\operatorname{Re}(Z_o)]\operatorname{Im}\Gamma_L}{\exp(2\alpha d)\left\{1-|\Gamma_L|^2\exp(-4\alpha d) - 2[\operatorname{Im}(Z_o)/\operatorname{Re}(Z_o)]\operatorname{Im}[\Gamma_L \exp(-2\gamma d)]\right\}} \tag{8}$$

For $\Gamma_L = 0$, $\eta_{21} = \exp(-2\alpha d)$.

A comparison of Eq. (8) with Eq. (3) yields the results

$$\ell_{21} = 1/\eta_{12} \tag{9}$$

$$\ell_{12} = 1/\eta_{21} \tag{10}$$

where η_{12} and ℓ_{12} are the line's efficiency and available loss factor, respectively, when the load Z_L at port 2 is interchanged with the source Z_g. Eqs. (9) and (10) are valid for any linear, reciprocal two-port network[6].

For the conditions of Eq. (1), $f = \ell_{21} = \ell_{12} \equiv \ell$ and $\eta_{21} = \eta_{12} \equiv \eta$. For such conditions, Eqs. (3), (4), and (9) reduce to the results given by Eq. (1).

The effect of impedance mismatch upon the available loss factors ℓ_{21} or ℓ_{12} is shown in figure 2 for a 10m length of RG-58U 50 ohm coaxial line at 30 MHz and $\mathrm{Im}\Gamma = 0$. The voltage reflection coefficient $\Gamma = \Gamma_g$ when computing ℓ_{21} and $\Gamma = \Gamma_L$ when computing ℓ_{12}. The available loss figure $= 10 \log_{10}(\ell_{21} \text{or } \ell_{12})$ is increased by 3 dB when Γ is increased from 0 to approximately 0.8. The available loss figure is increased by 10, 20, and 30 dB for $|\Gamma| = 0.980, 0.998$, and 0.9998, respectively.

The available loss figures of RG-58U line at 30 MHz for $\Gamma = 0$, 0.9991, and 0.9991 exp (-j0.100) are 8×10^{-5} dB, 0.04 dB, and 1.5 dB, respectively, for a line length of 10^{-2}m and 0.08 dB, 10.7 dB, and 26.5 dB, respectively, for a line length of 1m (see figure 3).

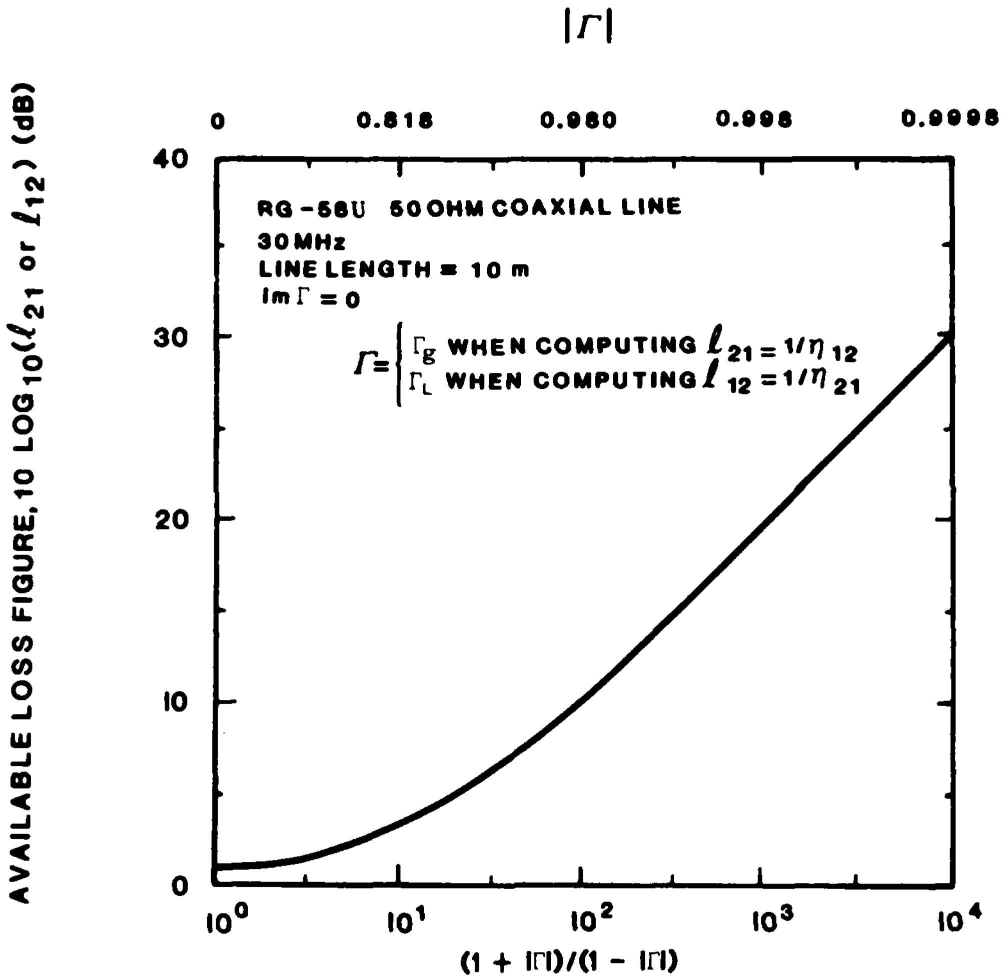

Figure 2. Available Loss Figure Dependence Upon Voltage Reflection Coefficient Γ

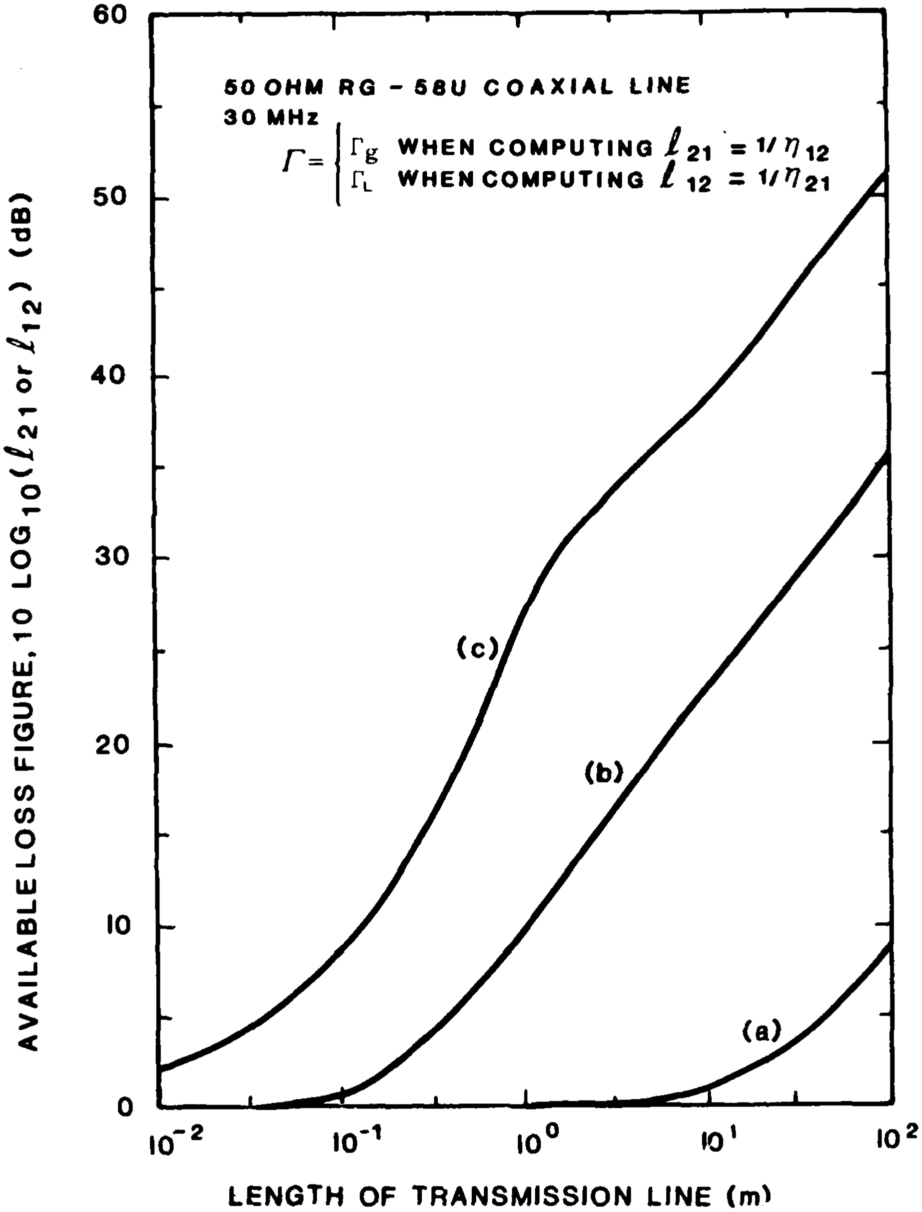

Figure 3. Available Loss Figure Dependence Upon Line Length
(a) $\Gamma = 0$
(b) $\Gamma = 0.9991$
(c) $\Gamma = 0.9991 \exp(-j\ 0.100)$

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